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A clinical comparison of subjective autorefractors to conventional refraction

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Abstract

The performance and cost effectiveness of two automatic refractors with subjective refinement capability was evaluated. Using a group of 125 patients, the results of the objective autorefraction and its subjective refinement by a technician were compared to the results of a conventional subjective examination. The objective autorefraction spherical equivalent differed from the conventional subjective by 0.50 D or less in 72% of eyes for the Humphrey 570, and 85% of eyes for the Marco 1600. The subjective refinement of the autorefraction resulted in a spherical equivalent difference of 0.50 D or less in 80% of eyes for the Humphrey and 84% of eyes for the Marco. The cylinder power difference was similar for both instruments and was 0.50 D or Jess in 82% of all eyes for objective autorefraction and 89% after subjective refinement. Objective autorefraction axis differences were generally small and were also similar for both instruments. There was no improvement in axis accuracy after subjective refinement. While subjective refinement did improve the accuracy of the autorefractors, the improvements were modest and probably not significant from a clinical standpoint. Even with subjective refinement, the instruments yielded large errors for some eyes. A cost analysis revealed the following: for a military clinic seeing 2000 patients per year, the autorefractors must save the practitioner 5.3 minutes per exam to be cost effective. This dropped to 3.6 minutes for the Marco, and 3.8 minutes for the Humphrey for a clinic seeing 6000 patients per year. If the instrument saves less than 3 minutes of examination time, then the technology is not cost effective regardless of patient volume.

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A CLINICAL COMPARISON OF SUBJECTIVE AUTOREFRACTORS TO CONVENTIONAL REFRACTION

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ABSTRACT

The performance and cost effectiveness of two automatic refractors with subjective refinement capability was evaluated. Using a group of 125 patients, the results of the objective autorefraction and its subjective refinement by a technician were compared to the results of a conventional subjective examination. The objective autorefraction spherical equivalent differed from the conventional subjective by 0.50 D or less in 72% of eyes for the Humphrey 570, and 85% of eyes for the Marco 1600. The subjective refinement of the autorefraction resulted in a spherical equivalent difference of 0.50 D or less in 80% of eyes for the Humphrey and 84% of eyes for the Marco. The cylinder power difference was similar for both instruments and was 0.50 D or less in 82% of all eyes for objective autorefraction and 89% after subjective refinement. Objective autorefraction axis differences were generally small and were also similar for both instruments. There was no improvement in axis accuracy after subjective refinement.

While subjective refinement did improve the accuracy of the autorefractors, the improvements were modest and probably not significant from a clinical standpoint. Even with subjective refinement, the instruments yielded large errors for some eyes.

A cost analysis revealed the following: for a military clinic seeing 2000 patients per year, the autorefractors must save the practitioner 5.3 minutes per exam to be cost effective. This dropped to 3.6 minutes for the Marco, and 3.8 minutes for the Humphrey for a clinic seeing 6000 patients per year. If the instrument saves less

than 3 minutes of examination time, then the technology is not cost effective regardless of patient volume.

KEY WORDS: autorefraction, autorefractors, automated refraction, cost effectiveness, objective refractors, subjective refractors, refraction

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INTRODUCTION

Statement of the Problem

The latest generation of autorefractors now have subjective refinement capability of sphere, cylinder and axis. Manufacturers state that these instruments can be operated by a technician with minimal training, and that the instruments are accurate and cost effective. A clinical comparison of two subjective autorefractors to conventional refraction was performed to evaluate the accuracy and cost effectiveness of subjective autorefractors.

Background Information

Automated refractors with subjective refinement are marketed to eye care professionals on the basis of accuracy, convenience, ease of use, efficiency, and cost effectiveness.[1,2] Using one instrument, a technician can measure aided and unaided visual acuity, interpupillary distance, perform an objective refraction with subjective refinement, and gather contrast sensitivity test data and glare test data. The manufacturers state the utilization of a subjective autorefractor by a technician will save the practitioner time and thus be cost effective. There is considerable debate and controversy in the literature on the practicality of autorefractors in clinical practice; however, there is

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[1] Information Brochure, "Humphrey Auto Refractor", 1991, Allergan Humphrey, 2992 Alvarado St., San Leandro, CA 94577

[2] Information Brochure, "Marco AR-1600G Automated Refractor", 1992, Marco Technologies, 11825 Central Parkway, P.O.Box 16938, Jacksonville, FL 32245-6938

little information regarding the practicality of autorefractors with subjective refinement capabilities.

Automatic infrared eye refractors were introduced for clinical use in 1971. Since that time, the instruments have been extensively refined. The first generation autorefractors, such as the Acuity System's 6600 Auto-Refractor and the Dioptron, took up to one minute per eye to measure ametropia. The second generation of autorefractors was introduced by Humphrey Instruments. This and similar instruments measured ametropia and allowed for a subjective measurement of visual acuity obtained through the proposed corrective lenses. In addition, a subjective refinement of spherical power was possible. The third generation of autorefractors was developed in Japan in 1980. This generation was characterized by an extremely rapid measurement time of less than one second, obtained by omitting the focus control loop system. The fourth and latest generation of autorefractors was introduced in 1983 by Marco/Nidex. In addition to objectively measuring ametropia, a subjective refraction program was incorporated utilizing conventional refractive techniques.

The general consensus in the literature is that the differences in accuracy between autorefractors of different manufacturers have become very small on normal subjects. A comparative study of seven autorefractors showed that the spherical equivalent was within 0.50 D in 80% of the cases from the conventional subjective refraction. Cylinder power was within 0.50 D in 90% of the cases, and axis errors were within 0.50 D in more than 84% of the cases (where axis error in diopters = 2 x cylinder power x sin(axis difference in degrees)).[3] A clinical evaluation of the Humphrey autorefractor gave similar results.[4]

There is also consensus in the literature that though the accuracy is fairly high, autorefractor results cannot be prescribed. There are too many large errors to make prescribing autorefractor results viable, and the instruments are not capable of binocular testing.[5,6,7]

The apparent value of an autorefractor is to produce a close refractive approximation from which to start the subjective refinement. This starting point would allow the clinician to save time by performing an abbreviated exam. However, there is not consensus in the literature that autorefractors save time. In a comparison of retinoscopy with autorefractors, Adler and Karania concluded that retinoscopy was faster and more accurate than autorefraction and, though they did not perform an economic analysis, they questioned the economics of autorefractors.[8]

Griffiths concluded that the use of autorefractors could not be justified as a means of achieving a refraction alone. He believed the real justification for its use was in satisfying the patient's perception that automation represented high clinical standards and

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[3]Wesemann, W., Automatic Infrared Refractors, A Comparative Study, *American Journal of Optometry*, August, 1987, V. 64, No. 8, p627-637

[4]Yeow, P. T., Clinical Evaluation Of the Humphrey Autorefractor, *Ophthalmic and Physiological Optics*, April 89, V. 9, No. 2, p. 171-175

[5]Wesemann, W., Automatic Infrared Refractors, A Comparative Study, *American Journal of Optometry*, August, 1987, V. 64, No. 8, p627-637

[6]Griffiths, G., Autorefractors, Their Use and Usefulness, *Optician*, 9 December, 1988, V. 196, No. 5178, p. 22-27

[7]Tunnacliffe, A., Is It Safe To Prescribe Autorefractor Results, *Optician*, 9 June 1989, V. 197, No. 5203, p. 23-28

[8]Adler, A., Autorefractors and Conventional Retinoscopy, *Optician*, 12 January 1990, V. 199, No. 5233, p. 16-21

those without automation would be judged poorly.[9] Other practitioners disagreed, claiming autorefractors helped obtain more refined prescriptions, saved time, and provided a greater level of service. These authors stated that autorefractors increased office efficiency and gave the doctor the potential to see more patients.[10,11]

In evaluating autorefractors, the most important parameter is the accuracy of measurement. To improve the accuracy of measurement, manufacturers have incorporated a subjective refraction capability into the instrument. Two autorefractors with subjective refinement capabilities are the Humphrey Model 570 and the Marco AR 1600.

The Humphrey Model 570 works according to the optical principle that a light spot imaged sharply onto the retina will be reflected back exactly on the light source itself. Located right next to the light source is a photodetector. The photodetector system analyzes the light signal and determines when the retinal image is in focus. The spherical ametropia is compensated by a double mirror Badal system, and two variable cross cylinder lens systems correct the astigmatism. The spherical subjective refinement is accomplished by using red/green and/or conventional fogging techniques. The cylinder subjective refinement can be accomplished by one of two methods: 1) Humphrey's patented three bar "Precision

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[9]Griffiths, G., Autorefractors, Their Use and Usefulness, *Optician*, 9 December, 1988, V. 196, No. 5178, p. 22-27
[10]Reto, S., Automated Refractors Can Help Build Your Practice, *Optometric Management*, June 1989, Vol 25, No. 6, p. 66-67
[11]Gibbs, A., Autorefractors, Friend or Foe, *Optician*, 8 March 1991, V. 201, No. 5291, p. 27-35

Astigmatic Measurement Test" (PAM); or, 2) utilizing the Jackson cross cylinder technique.

The Marco AR 1600 works according to Scheiner's double pinhole principle. Two light emitting diodes light up an aperture, which is then imaged on the retina. An opto-electric detection system determines when the two points of light are coincident on the retina. This gives a refractive error measurement for that meridian. The illumination system is then rotated to measure the different meridians. This system measures refractive error in 0.5 seconds, so it is critical that accommodation be relaxed at the time of measurement. To assure this, the instrument has a built in fogging procedure that is activated prior to the objective measurement. The spherical subjective refinement is accomplished by using red/green and /or conventional fogging techniques. Cylinder subjective refinement is accomplished by utilizing the conventional Jackson cross cylinder technique.

METHODOLOGY

The accuracy of measurement was determined by comparing the results of the objective autorefraction (OAR) and the subjective autorefraction (SAR) refinement with a conventional subjective refraction. All measurements were performed on 125 consecutive patients presenting to the Madigan Army Medical Center Optometry Service for vision care. This environment was selected for the following reasons:

1. It would allow the evaluation of the instrument's performance in a multi-technician/clinician environment;
2. There was a large and varied patient population; and
3. The high patient volume allowed for the gathering of a statistically significant sample in a relatively short period of time.

The patient population consisted of active duty soldiers and their family members; as well as military retirees and their family members. The patients' ages varied between 6 and 81 years with a mean of 23 years and a standard deviation of 14 years. Using the subjective refraction as the standard, spherical ametropia varied between -7.25 to +6.50 D with a mean of -1.00 D and a standard deviation of 1.9 D. The mean cylinder power was -0.50 D with a standard deviation of 0.75 D, and did not exceed -4.50 D.

The autorefractions and their subjective refinements were performed by military ophthalmic technicians. While military ophthalmic technicians are well trained, their training in subjective refraction is limited. The technicians were given one week of training and practice on the instruments prior to the examination of study patients. Half the patients started with the Marco, and half with the Humphrey, in an alternating pattern, followed by a conventional subjective refraction. The autorefractions and their subjective refinement were performed according to the manufacturers instructions (Appendix 1).

The data gathered included:

1. The objective measurement of sphere, cylinder and axis for each eye;

2. The subjective refinement of sphere, cylinder and axis for each eye;

3. The time elapsed from positioning the patient at the autorefractor until the print-out of data;

4. The best visual acuity refraction (BVA) by conventional refractive techniques in sphere, cylinder and axis for each eye;

5. The time required to obtain the BVA, from positioning the phoropter until recording of the BVA refraction; and

6. The patient's age and any medical/ocular conditions affecting vision.

The "Best Visual Acuity" refraction was determined by experienced, hospital credentialed, staff optometrists using conventional refractive techniques. The staff optometrists were unaware of the autorefractor outcomes. The objective autorefraction and the subjective autorefraction were compared to the subjective refraction using frequency histograms and simple descriptive statistics.

Accuracy of Measurement Criteria

There is general consensus in the literature that the following measurements be used to compare one refraction to another:

1. Spherical Equivalent Difference: Differences in the spherical equivalent is a broad measure of overall performance. The "spherical equivalent error (SE Error)"

$$\text{SE Error} = (S_a + {}^1/_2C_a) - (S_s + {}^1/_2C_s)$$

where S_a denotes the autorefractor sphere power; C_a denotes the autorefractor cylinder power; S_s denotes the subjective sphere power; and C_s denotes the subjective cylinder power. A negative value indicates that more minus was indicated by the autorefractor.

2. Cylinder Difference: The "cylinder difference error (C Error)" is calculated by

$$C \text{ Error} = C_a - C_s$$

A negative cylinder error indicates that more minus cylinder was indicated by the autorefractor.

3. Axis Difference: There is not general consensus in the literature on how cylinder axis differences should be treated. It is apparent that a 10^o axis difference has more significance when the cylinder power is -2.50 D than when the cylinder power is -0.25 D. Taking the simple algebraic difference is a poor description of axis difference. The cylinder power must also be taken into consideration when evaluating cylinder axis differences. Wesemann and Rassow have proposed the following measure to analyze cylinder axis differences:[12] The "axis error (A Error)" is

$$A \text{ Error (in Diopters)} = 2C_s\sin(\text{axis difference})$$

This formula weights the actual axis difference in degrees with the subjective cylinder power and has the advantage that all results can be compared regardless of the actual cylinder powers. For example, an astigmatism of -0.50 D with a 14.5^o axis difference gives an Axis Error of -0.25 D. To have the same -0.25 D axis error, an astigmatism of -2.00 D would have to have an axis difference of 3.5^o.

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[12]Wesemann, W., Automatic Infrared Refractors, A Comparative Study, *American Journal of Optometry*, August, 1987, V. 64, No. 8, p627-637

The Axis Error measurement described above does have limitations, however. If the subjective cylinder power is zero, then the Axis Error is always zero regardless of the magnitude of the autorefractor cylinder axis difference.

The ideal measure of axis error should take into account the difference in cylinder power as well as the difference in axis. Again, Wesemann and Rassow have derived a measure that they call the "total cylindrical difference (TCD)":

$$TCD = \text{Square Root}(C_a^2 + C_s^2 - 2C_aC_s\cos(2[\text{axis difference}]))$$

This measure weights the difference of the cylinder powers with the axis difference. The TCD is always positive, as it is calculated as the absolute value of the vector difference between both cylinder corrections. Now if the subjective measurement of cylinder power is zero, then the TCD is the cylinder power of the autorefraction. Conversely, if the cylinder power of the autorefraction is zero, then the TCD is the cylinder power of the subjective. The drawback to the TCD is that the measure is not intrinsically familiar to the practicing optometrist, but a short study of the TCD reveals its elegance in accounting for both a cylinder power difference and a cylinder axis difference.

Cost Effectiveness Criteria

The basic formula for studying cost is:

Total Cost = Fixed Costs + (Variable Costs) x (# of patients)

where:

Fixed Costs = Yearly instrument cost and service contract, and

Variable Costs = (Procedure time (min)) x (labor cost ($/min)) x (patients/year).

The break-even point occurs when the total cost of the procedure performed by the doctor equals the total cost of the procedure performed by the technician using the autorefractor. By setting the two total cost formulas equal to each other, then the following patient break even-formula is derived:

Patient Break-Even = (Fixed Cost of Automation) ÷ (Doctor labor costs x assumed time saving - technician labor costs x procedure time)

The formula used to calculate the minimum time that must be saved in order to achieve a break-even point is:

Minimum time = (Technician labor costs x procedure time) ÷ Doctor labor costs

RESULTS AND DISCUSSION

Accuracy of Measurement

Histograms were chosen to present the data because they offer several advantages. First, the percentage distribution around zero shows how often the autorefraction and their subjective refinement are in agreement with the subjective. Second, the histograms show how many large errors occurred. Third, the frequency distributions reveal systematic deviations from the result of the subjective refraction. Fourth, the benefit of subjective refinement can be easily seen in the histogram.

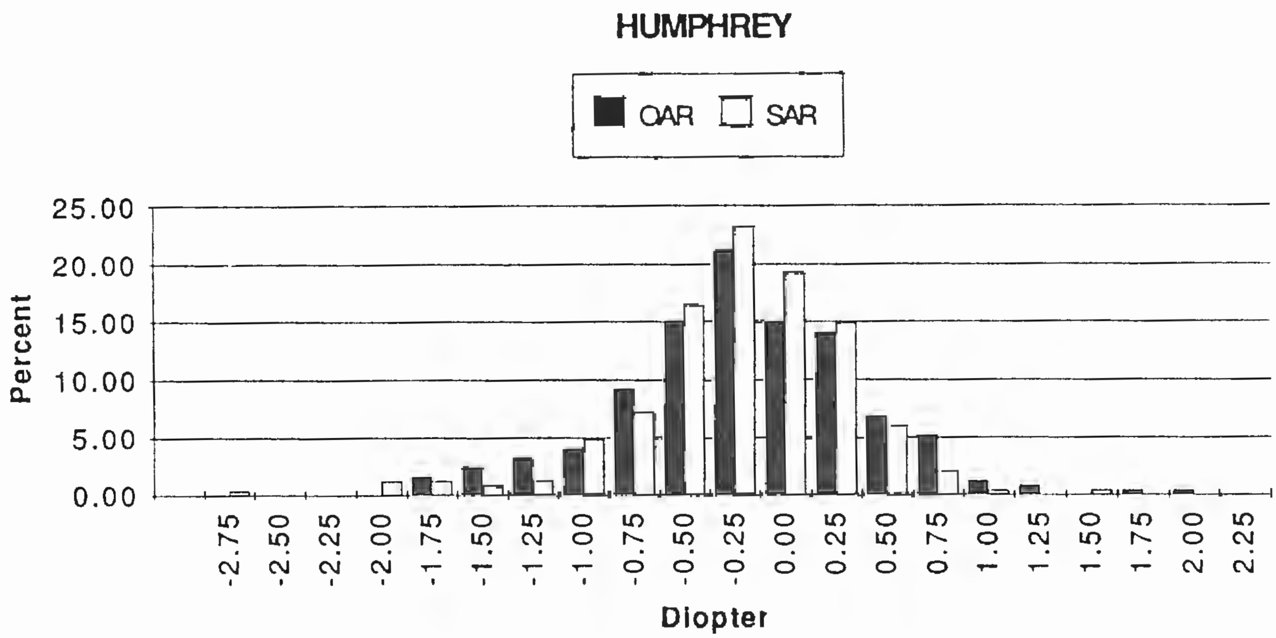
The frequency distributions of the differences between the objective autorefraction (OAR), the subjective autorefraction (SAR), and the subjective refraction, are plotted in histograms (Figures 1 to 4).

Figure 1 shows spherical equivalent error distribution. The Humphrey shows a systematic error of -0.25 D for both the objective autorefraction and its subjective refinement. The Marco is equally distributed around zero for both the objective autorefraction and its subjective refinement. The purpose of subjectively refining the autorefraction is to increase the accuracy of the refraction. The desired result would be a histogram with a much higher frequency around zero having a reduced distribution. It is apparent that the subjective refinement is not much better than the objective autorefraction. Both autorefractors produced errors up to 2.75 D during objective autorefraction, and those errors were not always corrected by subjective refinement.

Figure 2 shows the cylinder power error distribution. Both the Humphrey and the Marco show a systematic error of -0.25 D with autorefraction. This tendency for both instruments to objectively measure higher cylinder power should not necessarily be interpreted as an error because the optometrists may have been biased towards minimizing cylinder power. The subjective refinement eliminated this systematic error; however, there was very little improvement in distribution. One can also observe that occasionally errors as high as 3.00 D occurred.

Figure 3 shows that the axis error distribution for both instruments is similar. The autorefraction gives an axis error that is 0.50 D or less in over 90% of the eyes. Subjective refinement resulted in no improvement in autorefractor accuracy. While the

FIGURE 1 Spherical Equivalent Error Distribution



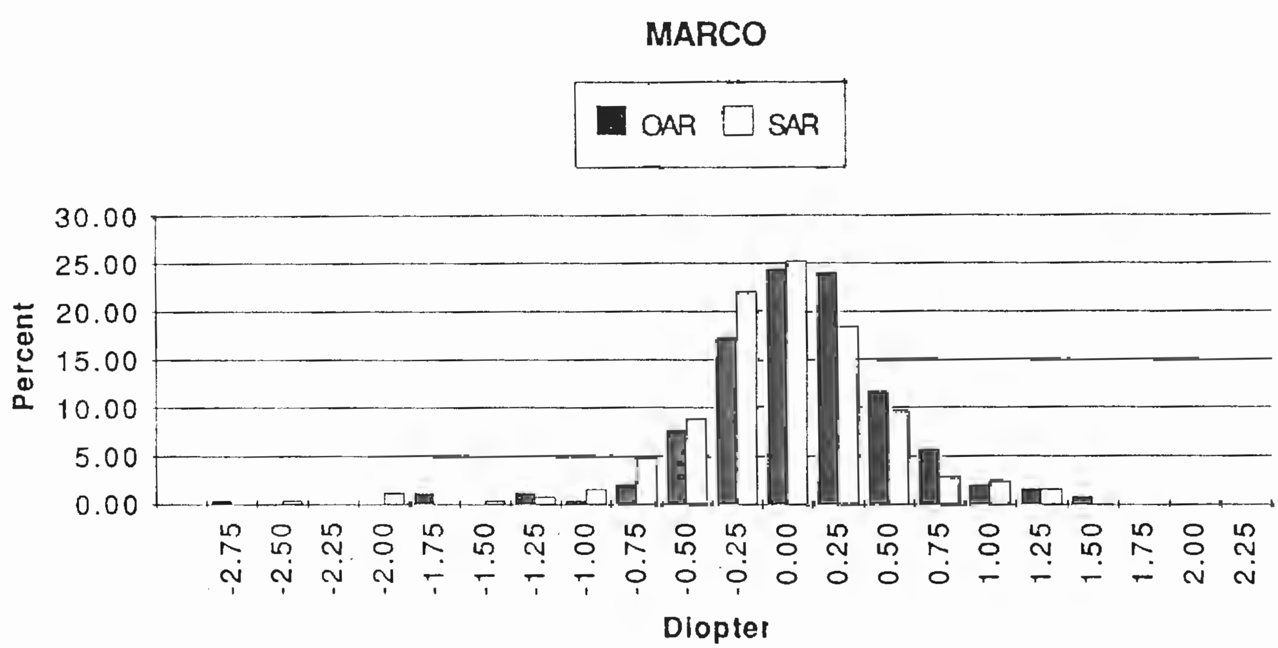
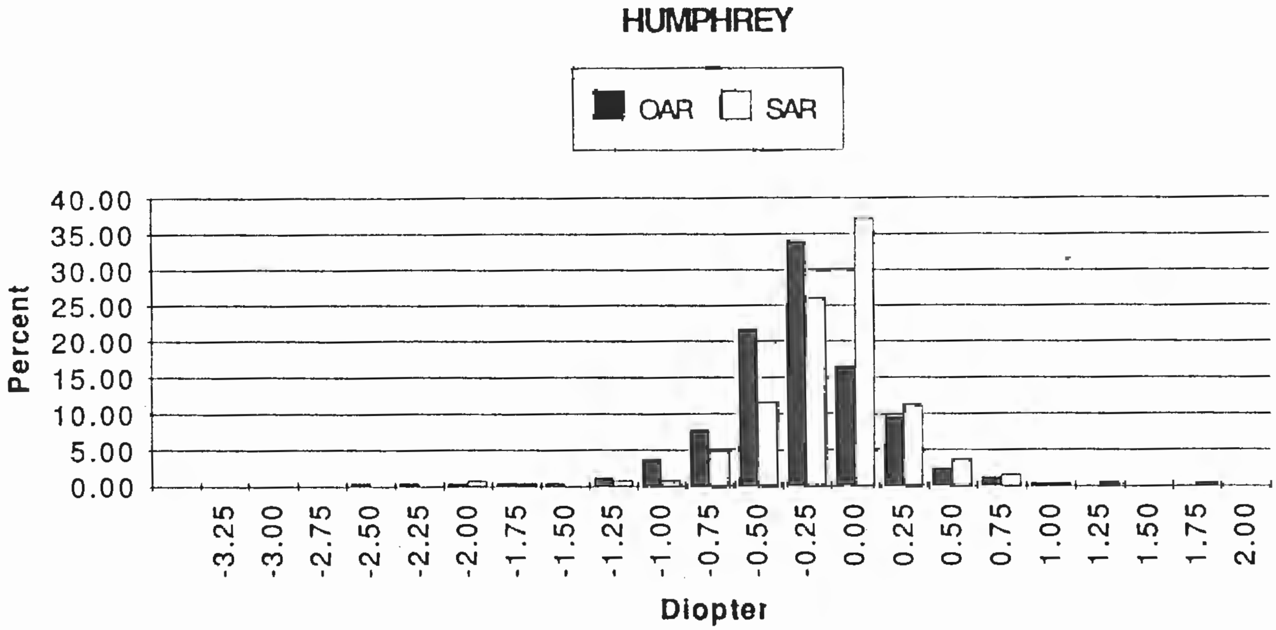


FIGURE 2 Cylinder Power Error Distribution



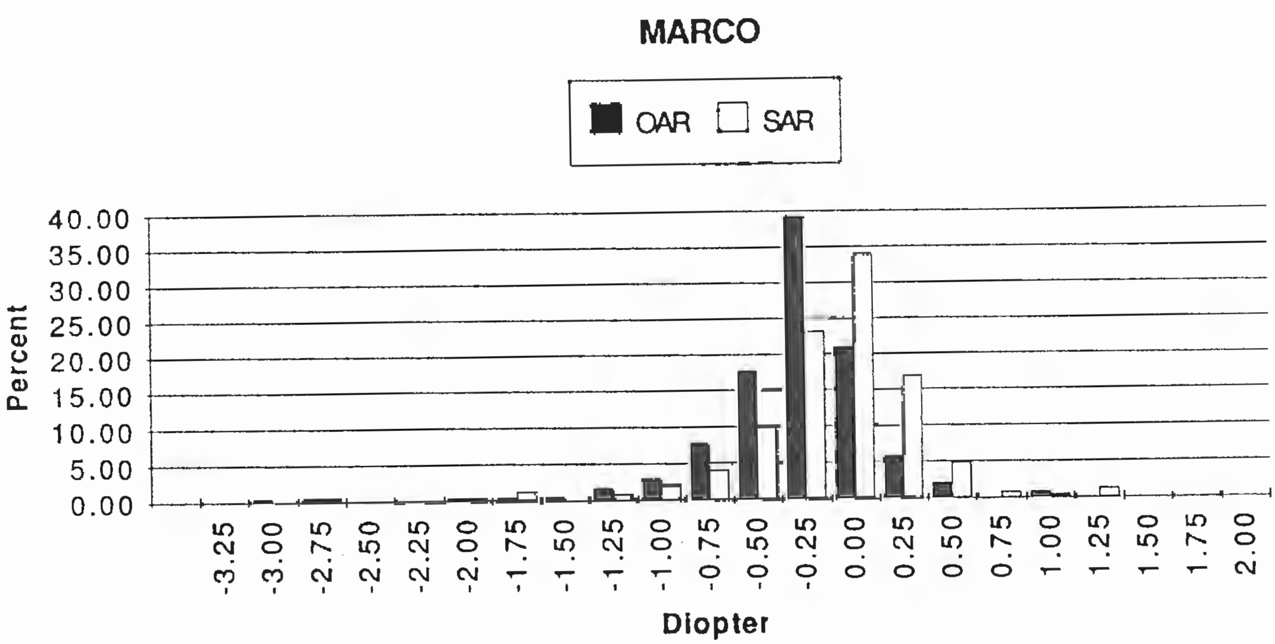
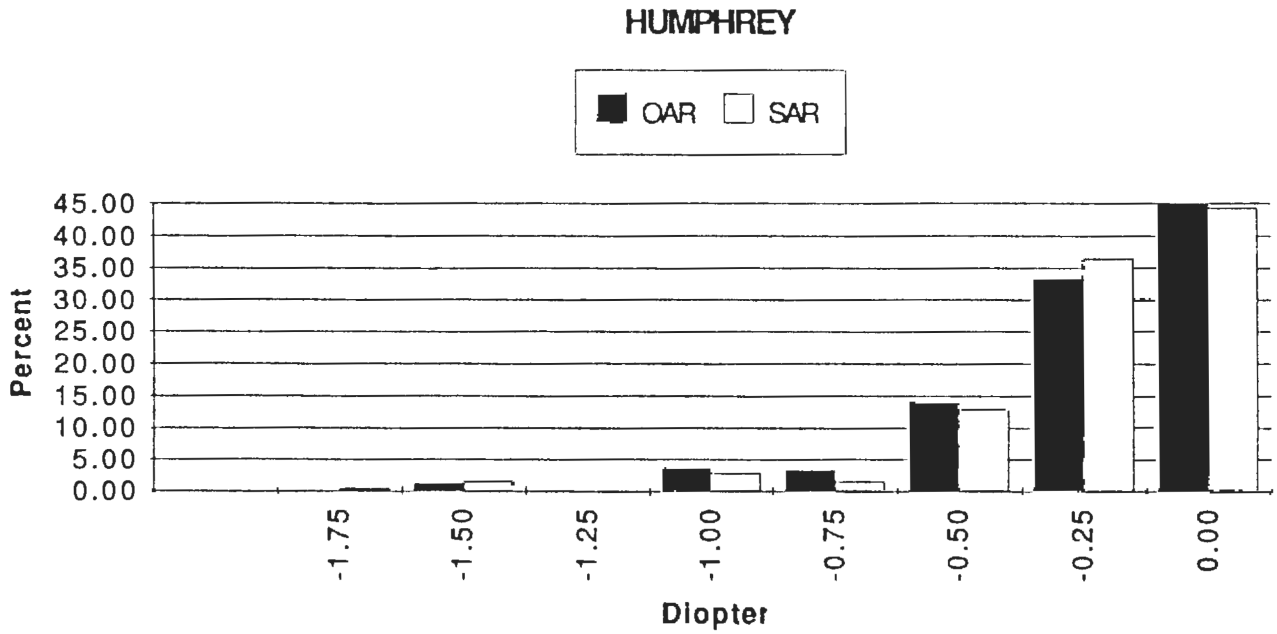
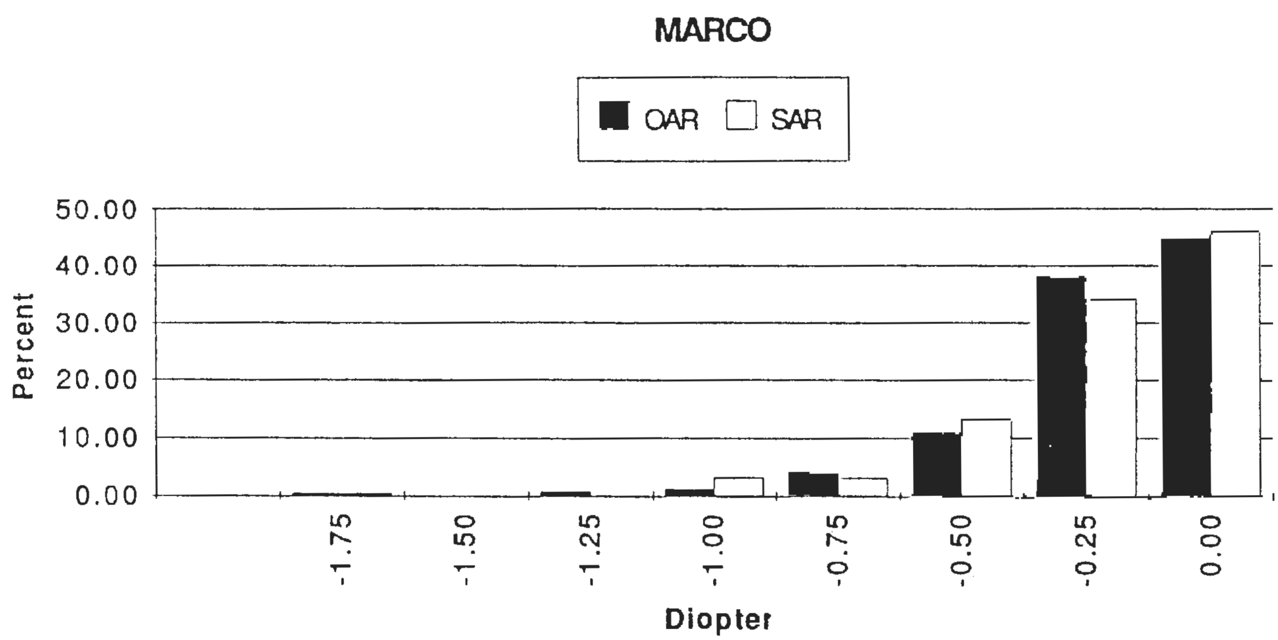


FIGURE 3 Axis Error Distribution





instruments usually did very well in this performance measure, errors as high as -1.75 D still occurred.

Figure 4 shows that the total cylindrical difference for both instruments is similar. Subjective refinement resulted in minimal (approximately 4%) improvement in autorefractor accuracy. Autorefractors are generally more accurate at determining cylinder power and axis than sphere power; however, total cylindrical difference errors as high as -3.75 D occurred.

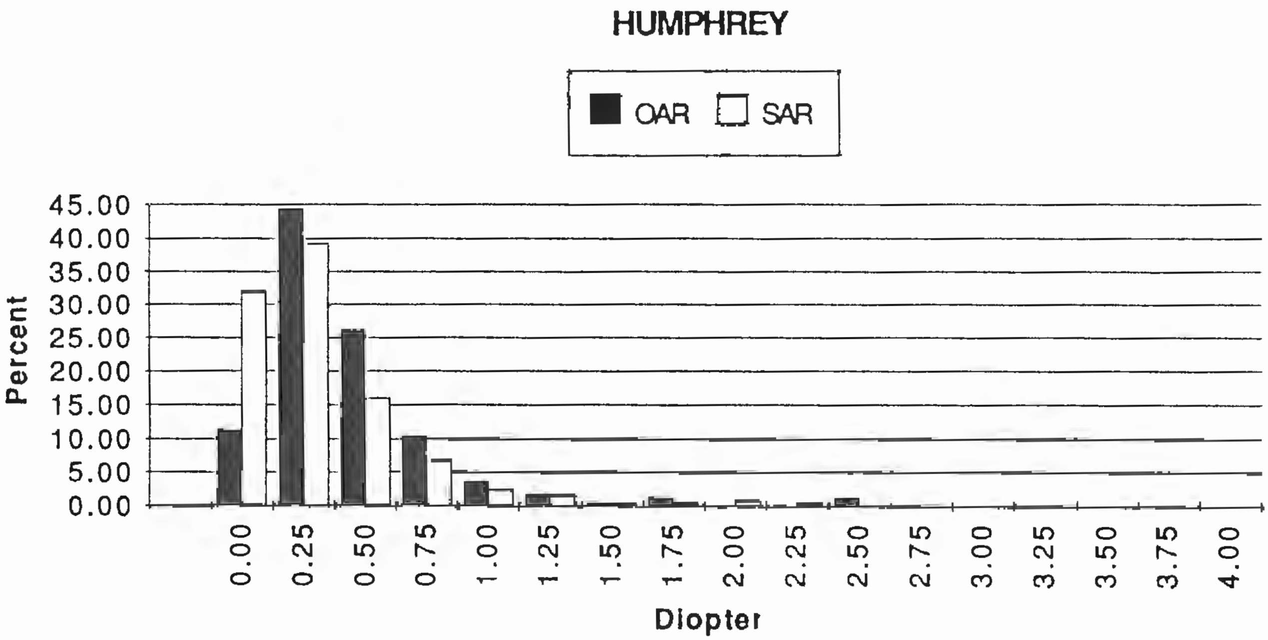
The histograms are summarized in Table 1.

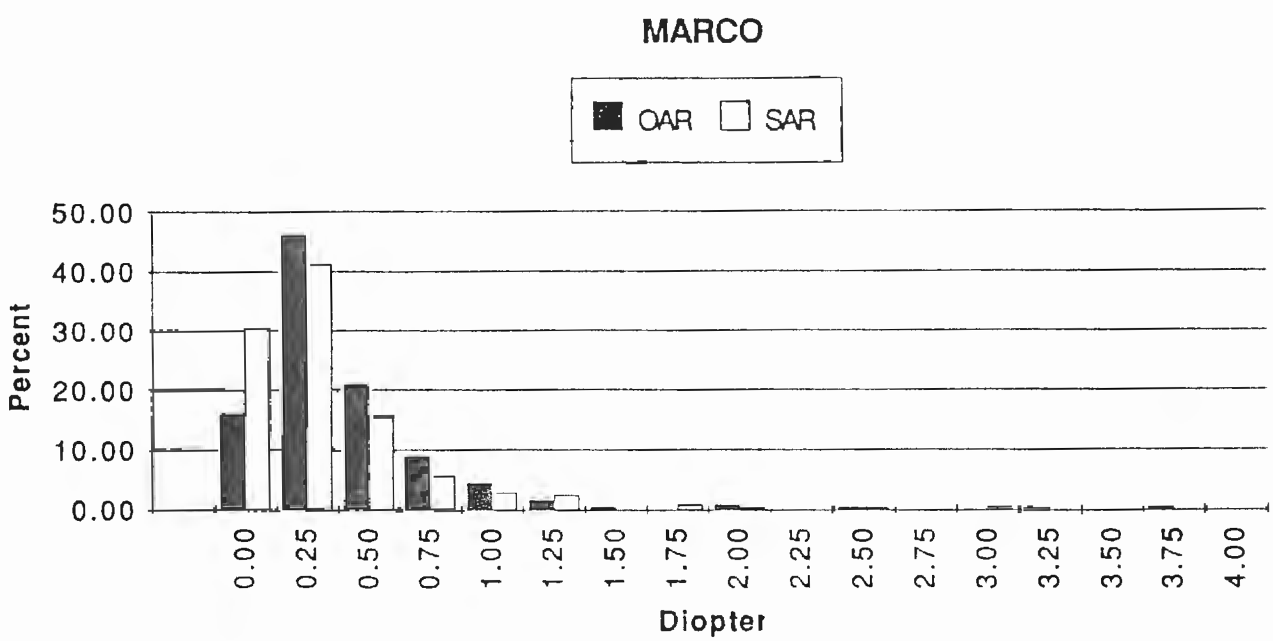
Table 1. Summarizing Table on Autorefractor Accuracy

Instrument	Sphere SE 0.50 D (%)	Cylinder C 0.50 D (%)	Axis A 0.50 (%)	Astigmatism TCD 0.50 (%)
Humphrey OAR	72	82	92	82
Humphrey SAR	80	90	94	87
Marco OAR	85	85	93	83
Marco SAR	84	89	93	87

Table 1 indicates the number of refractions in which the difference between the results of the autorefraction and the subjective refinement differed from the subjective by 0.50 D or less. For the Humphrey, 72% of the objective autorefraction spherical equivalents were within 0.50 D. The subjective refinement improved this to 80%. For the Marco, 85% of the autorefraction spherical equivalents were within 0.50 D, with no improvement gained with subjective refinement. The results of the cylinder difference, axis difference, and total cylindrical difference

FIGURE 4 Total Cylindrical Difference





are essentially the same for both the Marco and the Humphrey, with subjective refinement offering minimal or no improvement.

The differences between the objective autorefractions (OAR) and the subjective autorefractions (SAR) for the four measures are described in Table 2.

Table 2 Difference between OAR and SAR

	SPHERICAL EQUIVALENT DIFFERENCE				CYLINDER ERROR DIFFERENCE			
	Humphrey		Marco		Humphrey		Marco	
	OAR	*SAR*	*OAR*	*SAR*	*OAR*	*SAR*	*OAR*	*SAR*
Mean	-0.13	-0.20	0.13	0.02	-0.29	-0.13	-0.30	-0.12
Standard Error	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Median	-0.13	-0.13	0.13	0.00	-0.25	0.00	-0.25	0.00
Mode	-0.13	-0.13	0.13	0.00	-0.25	0.00	-0.25	0.00
Standard Deviation	0.60	0.60	0.51	0.51	0.44	0.41	0.44	0.46
Variance	0.36	0.36	0.26	0.26	0.19	0.17	0.19	0.21
Kurtosis	0.84	5.14	4.85	3.43	4.70	5.62	10.05	6.46
Skewness	0.02	-1.46	-1.00	-0.84	-1.09	-0.52	-1.95	-1.35
Range	3.75	4.75	4.13	3.75	3.50	3.75	4.00	4.00
Minimum	-1.75	-3.13	-2.63	-2.38	-2.50	-2.00	-3.00	-2.75
Maximum	2.00	1.63	1.50	1.38	1.00	1.75	1.00	1.25

	AXIS ERROR DIFFERENCE				TOTAL CYLINDRICAL DIFFERENCE			
	Humphrey		Marco		Humphrey		Marco	
	OAR	*SAR*	*OAR*	*SAR*	*OAR*	*SAR*	*OAR*	*SAR*
Mean	-0.16	-0.16	-0.13	-0.15	0.48	0.35	0.45	0.36
Standard Error	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.03
Median	-0.04	-0.04	-0.03	-0.04	0.38	0.25	0.30	0.25
Mode	0.00	0.00	0.00	0.00	0.25	0.00	0.25	0.00
Standard Deviation	0.26	0.27	0.22	0.23	0.39	0.37	0.44	0.40
Variance	0.07	0.07	0.05	0.05	0.15	0.14	0.20	0.16
Kurtosis	7.99	11.18	11.56	8.20	11.09	8.69	22.54	13.41
Skewness	-2.64	-3.08	-2.89	-2.51	2.78	2.41	3.89	2.98
Range	1.48	1.61	1.62	1.62	2.68	2.48	3.86	3.08
Minimum	-1.48	-1.61	-1.62	-1.62	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	2.68	2.48	3.86	3.08

Analyzing the spherical equivalent difference reveals that the Humphrey tended to overminus slightly during objective autorefraction while the Marco tended to overplus slightly. Subjective autorefraction resulted in a small (≤0.12 D) shift toward minus for both instruments. The objective autorefraction standard deviation was 0.51 D for the Marco and 0.60 for the Humphrey. Subjective autorefraction did not reduce the standard deviation; therefore, subjective refinement did not reduce the distribution of errors. In analyzing cylinder error differences, axis error differences, and the total cylindrical difference, there was very little difference in performance between the two instruments with subjective refinement resulting in either small or minimal improvements in accuracy.

Cost Effectiveness

For a new, technologically advanced instrument to be cost-effective, it must gather the same information at lower cost than an alternative method. Though there is not a consensus in the literature, it is assumed that an autorefractor will save the doctor time. The autorefraction may replace retinoscopy and allow the doctor to perform an abbreviated refraction with no loss of accuracy.

Cost analysis assumptions and data are listed in Appendix 2. By studying the various cost analysis formulas, one can see that the results can change dramatically depending on labor costs assumed for the technician and doctor, on equipment cost, and on patient volume. For example, if the doctor's salary is higher, or the technician's is lower, then the equipment becomes cost effective at a lower patient volume. In this analysis, a military "model" clinic was assumed. The ophthalmic technician had 10 years of experience with a pay grade of E-5 (salary of $31,000 per year), and the optometrist had 10 years experience with a pay grade of O-4 (salary of $52,000 per year). Equipment cost was determined using the manufacturer's suggested retail price. Accepted accounting principles were applied to determine yearly instrument cost (assuming a ten year straight line depreciation schedule with no residual value) and the cost of a yearly maintenance contract was added.

Cost analysis revealed the following: for a military clinic seeing 2000 patients per year, the autorefractors must save the practitioner 5.3 minutes per exam to be cost effective. This dropped to 3.6 minutes for the Marco, and 3.8 minutes for the Humphrey for a clinic seeing 6000 patients per year, and to 3.3 minutes and 3.6 minutes respectively for a clinic seeing 10,000 patients per year. If the Humphrey saves less than 3.06 minutes of examination time, and the Marco saves less than 2.77 minutes, then the technology is not cost effective: there is no break-even point regardless of patient volume. Since the average subjective refraction was 6.48 minutes (Table 3), it is very unlikely that the instrument will save five minutes of examination time. It is evident that the clinic must have a high patient volume to achieve cost effectiveness.

Table 3. Average Procedure Time

TIME (Minutes)	*MARCO*	*HUMPHREY*	*SUBJECTIVE*
Mean	4.68	5.18	6.48
Standard Error	0.15	0.16	0.24
Median	4.40	5.00	5.50
Mode	4.00	5.00	5.00
Standard Deviation	1.66	1.73	2.61
Variance	2.75	2.99	6.80
Range	8.87	10.08	14.00
Minimum	1.38	1.92	3.00
Maximum	10.25	12.00	17.00

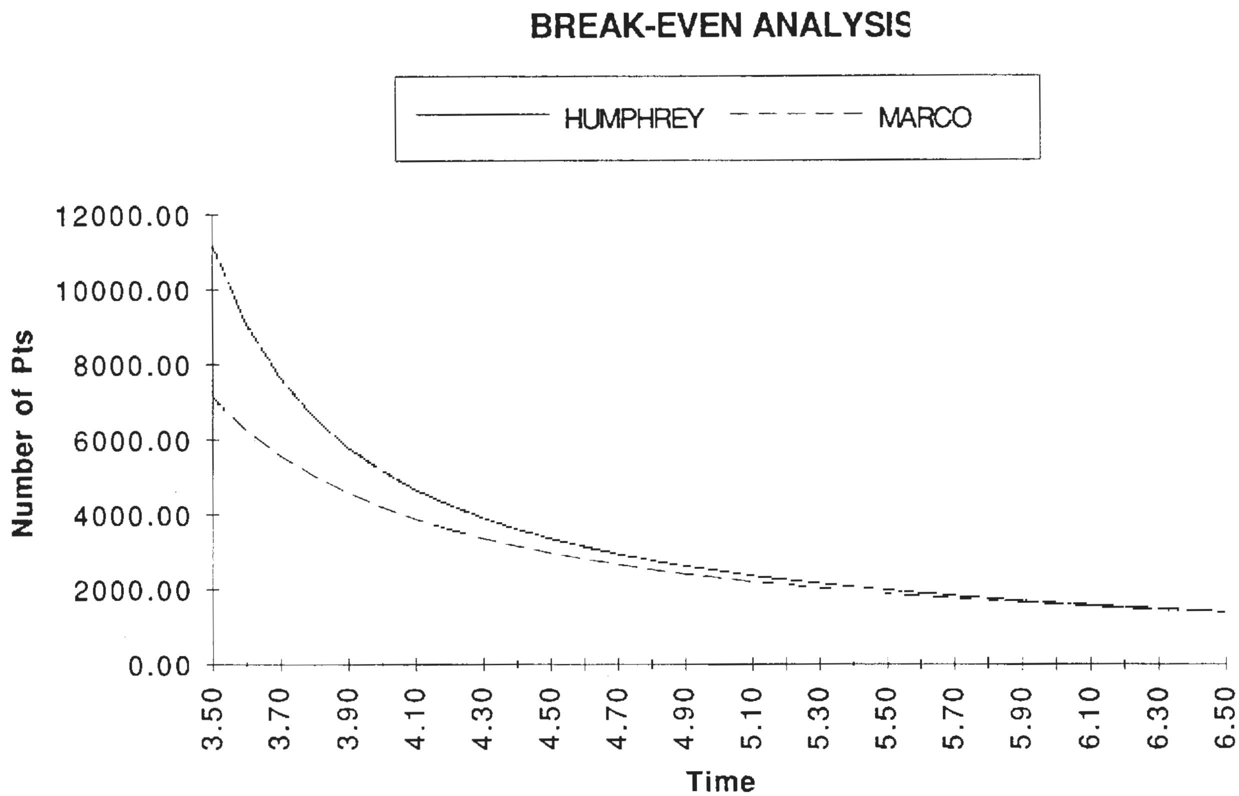
Break-even analysis is graphed for a time saving of 3.5 min to 6.5 min (Figure 5). This demonstrates that the less time saved, the more patients must be seen to achieve a break-even cost.

Another way of analyzing costs is to look at the cost per autorefraction per patient, as depicted in Table 4.

Table 4 Cost per Patient ($)

# of Patients	MARCO	HUMPHREY
1000	3.87	3.87
2000	2.62	2.70
3000	2.21	2.30
4000	2.00	2.11
5000	1.87	1.99
6000	1.79	1.91
7000	1.73	1.86
8000	1.69	1.81
9000	1.65	1.78
10000	1.62	1.76

FIGURE 5 Break-Even Analysis



Costs are slightly higher for the Humphrey because the autorefractor took more time than the Marco. Again, the cost per autorefraction is patient volume dependent: the more patients seen, the less the cost per autorefraction.

CONCLUSION

The results of this study revealed that the subjective refinement capability of autorefractors is of minimal value. An objective refraction could be performed by either instrument in less than two minutes. The subjective refinement increased total autorefractor time to an average of 5 minutes, which greatly increased costs. If the subjective refinement resulted in a significant increase in accuracy, the additional costs would be acceptable; however, accuracy was not improved significantly.

The decision to utilize an autorefractor in practice remains an individual one. In this study, the autorefractors give an objective refraction that is accurate to within 0.50 D approximately 80% of the time, and can be used as a starting point for the subjective refinement. This may save doctor time. Additionally, autorefractors can measure unaided and aided visual acuity, measure interpupillary distance, perform glare and contrast sensitivity measurement, as well as give an objective and subjective refraction. These other features can increase the utility and cost effectiveness of the autorefractors; however, the purpose in acquiring an autorefractor is primarily to perform an objective autorefraction.

This study shows that the addition of subjective refinement capability to autorefractors did not significantly increase accuracy, and this feature is not cost effective.

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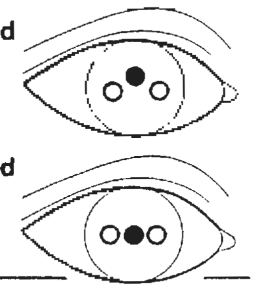
APPENDIX 1: Autorefractor Subjective Refinement Instructions

AUTOMATIC REFRACTOR MODEL 570 INSTRUCTIONS

Misaligned

Aligned



OBJECTIVE REFRACTION

STEP 1 Power up. Select set-up mode.
- Vertex: Contacts (0.00)
  Glasses/Unaided (13.5)
- Auto Plus (if under age 40)
- Mode: For automatic sequencing. Skip steps 3, 5–13.

STEP 2 Position patient using power table and chin cup so that eyes are level with silver mark on headrest. Instruct patient to lean forward against headrest.

STEP 3 Press **R. EYE.**

STEP 4 Use control ball to align flashing green light between yellow lights on patient's pupil. Release ball. Green light should now stop flashing.

STEP 5 Instrument will automatically make the depth adjustment. If the instrument hasn't positioned the green light properly between the yellow lights, use thumbwheel to again bring green light between yellow lights.
- Have patient fixate on acuity line in the instrument.

STEP 6 Press **READ**. Wait for "DATA" light to go off on control panel. Determine patient's visual acuity by pressing ↑ or ↓ to obtain the smallest acuity line the patient can read.

SUBJECTIVE REFRACTION

STEP 7 Press **TARGET** to go to R/G. Ask patient which letters are clearer; those in the red or green background. If green, proceed to **STEP 8a** or **8b**. If red, turn thumbwheel slowly toward you to decrease sphere power until patient reports that green is slightly clearer. Do not decrease sphere power more than .75 diopters. Some patients are non-responsive to the R/G test.

STEP 8 Cylinder power and axis can be refined by two methods. Depending upon your refractive preference, proceed to **STEP 8a** for the PAM Test or **STEP 8b** for the JCC Test.

STEP 8a Press **TARGET** to go to " ." Ask patient which line is darkest/sharpest:
- If center is sharpest and the two outside lines are equally grey, test is complete.
- If top line is sharpest, move thumbwheel up in.12D steps until center line is sharpest and top and bottom lines are equally blurred.
- If bottom line is sharpest, move thumbwheel down towards you until center line is sharpest and top and bottom lines are equally blurred.

Press ↑ once to go to " ." Repeat the question and thumbwheel procedure until patient indicates the center line is sharpest/darkest and the two outside lines are equally grey.

STEP 8b Press ↑ 1x for CC AXIS. Press **AXIS** and ask patient which is better, one or two? Instrument will indicate which direction to move thumbwheel. Begin with 10 degree shifts in axis, then 5. Endpoint is reached when patient finds readings approx. equal.

Press ↑ once for CC PWR. Press **CYL** and ask patient which is better, one or two?

Instrument will again indicate which direction to move thumbwheel. Use .25 Diopter changes until patient finds readings approx. equal.

STEP 9 Press **TARGET** again to return to R/G. Turn thumbwheel until patient reports Cs in Red and Green are, depending on your refractive preference, either: equally clear, slightly clearer in the red, or slightly clearer in the green.

STEP 10 Press **TARGET** again to return to the Acuity chart. Determine final acuity with ↑ and ↓.

SUBJECTIVE REFINEMENT
(Model 1600 only)

CHECKING VISUAL ACUITY

After completing the objective refraction you may check visual acuity by using the isolated Snellen lines. Depress the **SUBJECTIVE MODE SWITCH** and the 20/15 line of the Snellen Chart will be automatically placed into the patient's view. Simultaneously the small red LED next to the 20/15 line will become illuminated and the last objective measurement for that eye will be printed out for your reference.

Ask the patient to recite the 20/15 line. If they are unable to do so, depress the appropriate **SNELLEN CHART LINE SELECTOR SWITCH** ('up') which will enter the next larger Snellen line into the patient's view. If the determined visual acuity is not at a satisfactory level, the operator may wish to refine the objective readings

SUBJECTIVELY REFINING VISUAL ACUITY

At this point it must be understood that there are many different methods and techniques of subjective refinement. In reality the refinement process is a series of small refinements that progressively improve the patient's vision. The sequence of each step taken can vary from practitioner to practitioner and sometimes from patient to patient. A good working knowledge of each step will enable the operator to begin at a logical point for that particular patient, and then to proceed to completion.

The AR 1600 is automatically placed into the subjective refinement mode when the **SUBJECTIVE MODE SWITCH** is depressed. The objective reading that was last taken will be displayed, as well as printed. However, if three or more objective readings are taken, the median value will be the starting point for the subjective refinement.

Notice that as soon as the **SUBJECTIVE MODE SWITCH** is depressed that "SUBJ." is illuminated at the lower left of the digital display as well as a flashing "SPHERE" above the spherical reading. This flashing indicates that "SPHERE" can be changed by rotating the power wheel. You are now ready to begin subjective refinement.

A typical refinement might go as follows:

The operator has taken objective readings on both eyes and has decided on further refinement after the patient's unsatisfactory response to the isolated lines of the Snellen Chart. At this point a red/green balance test can be performed. Introduce the red/green target to the patient by either depressing the **RED/GREEN TARGET SELECTOR** or successively depressing the **SNELLEN CHART LINE SELECTOR SWITCH (▼).**

Fog the patient by adding plus 1.5 D (or more) of sphere to the displayed refraction. Rotate the **POWER ADJUSTMENT WHEEL** to do this. Carefully explain to the patient, "Let me know when the red and the green blocks are <u>equal</u> in brightness, but not necessarily in focus."

(NOTE: Some refractionists bypass the initial red/green test and proceed directly to the cylinder and axis refinement. However, they do place an additional plus .50 D sphere in front of the patient in order to make the cross cylinder test more defined. Also you may wish to forego the cross cylinder test and refine cylinder power and axis with the clock dial target.)

Now rotate the **POWER ADJUSTMENT WHEEL** so that you slowly return towards the original spherical refraction. At some point the patient should determine the best level of red/green balance. Re-introduce the Snellen Chart by depressing the **SNELLEN CHART LINE SELECTOR SWITCH (▲)** and ask the patient to recite the 20/15 line. If they are unable to do so, progressively introduce larger lines until you get a satisfactory response.

Ideally the patient should respond to 20/20 or better. If this is not the case, and an unsatisfactory V.A. is determined then you should refine cylinder power and axis.

Depress the **S/C/A SWITCH** and notice that the "axis" light begins to flash. Depress the **START BUTTON** to position the flip cylinder into the patient's view. Ask the patient: "Which is better, 'one' (already in view) or (depress **START** once) 'two'?"

As you depress the **START BUTTON,** notice that a corresponding arrow lights up in the display panel. If the patient likes the up arrow position (▲), increase the degree of axis (by rotating the power wheel). Likewise, decrease the degree for the down arrow position (▼).

Eventually, by repeating this procedure, the patient will narrow the difference between 'one' and 'two'. When the patient indicates that they are equal, you have determined the exact degree of axis.

To refine cylinder power, depress the **S/C/A** again until "cylinder" begins to flash. Again, use the flip cylinder to narrow the difference down to equal. However, now you will be increasing or decreasing cylinder power.

Depress the **S/C/A SWITCH** so that the sphere power can be changed. The 20/15 line of the Snellen Target will automatically return. At this point the patient should be able to read 20/20 or better. If not, you may have to fog the patient again with plus sphere and then proceed to achieve a balance between red and green. Recheck the final V.A. after balancing the red/green. If it is satisfactory, move to the second eye. The final V.A. will be entered into memory upon movement to the second eye (or in the case of refinement of the second eye, when proceeding to the next step).

Now move the instrument to the remaining eye and perform the above steps again. The previously taken objective readings for the remaining eye will be automatically entered as a base point for your subjective refraction.

APPENDIX 2: Cost Analysis Assumptions and Data

Formulas:

1. Total Costs = Fixed Costs + (Variable Costs) x (# of patients)

where:

Fixed Costs = Yearly instrument cost and service contract

Variable Costs = (Procedure time (min)) x (labor cost ($/min)) x (patients/year)

2. Patient Break-Even = (Fixed Cost of Automation) ÷ (Doctor labor costs x assumed time saving - technician labor costs x procedure time)

3. Minimum Break-even time = (Technician labor costs x procedure time) ÷ Doctor labor costs

Assumptions

Humphrey 570:

Purchase cost: $13500.00

Service Contract: $1000.00/year

Total yearly cost: $2350.00 (assuming straight line, 10 year depreciation with zero residual value + service contract).

Marco AR 1600G:

Purchase cost: $14995.00

Service Contract: $1000.00

Total yearly cost: $2499.50 (assuming straight line, 10 year depreciation with zero residual value + service contract).

Labor Costs:

Optometrist: $52000.00/year or $0.49242/minute

Ophthalmic Technician: $31000/year or $0.29356/min

(Assuming the optometrists and technician both work 8 hours/day for 220 days/year).